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Scenario Analysis for the Risk of Pine Shoot Beetle Outbreaks Resulting from the Movement of Pine Logs from Regulated Areas

U.S. Department of Agriculture
Animal and Plant Health Inspection Service

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Contents:

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Pest: *Tomicus (=Blastophagus) piniperda* (L.)
Coleoptera: Scolytidae (Bark Beetles)
Common Name: Pine Shoot Beetle (PSB)

Objective:

A quantitative characterization of the risks associated with the movement of pine logs from regulated areas and to identify the best combination of available mitigation measures that effectively reduce the risk of artificial spread to acceptable levels while also relieving the regulatory burden on the logging industry as much as reasonably possible. The product of this effort will provide the basis for changes in PPQ domestic quarantine regulations.

Pest Distribution: Europe, Asia, and the Great Lakes region of the United States

Background on the Situation:

PSB was discovered near Cleveland, Ohio in July 1992. It is now known to be established in six States: Illinois, Indiana, Michigan, New York, Ohio, and Pennsylvania. It is expected to continue spreading naturally.

Infested counties are currently regulated under Federal and State quarantines. At present, logs of pine trees can be transported from infested counties to non-infested areas from July 1 through October 31 with no restriction (most beetles are assumed to be in the shoots during this time - normal logging practice would remove all branches from the logs before moving to the sawmill). From November 1 through June 30, logs must be fumigated or processed at the destination within 24 hours of harvest (beetles are overwintering at the base of the tree during this time - the assumption is that beetles are destroyed during debarking/processing at the sawmill).

Early in 1994, the Michigan Dept. of Agriculture (MDA) proposed modifications to the current regulatory regime. PPQ rejected the proposal, resulting in a continuing discourse with MDA, PPQ, and the Forest Service about technical aspects of the proposal, options, and risk.

This document has been developed by PPQ to characterize the risks as the basis for decisionmaking associated with a regulatory proposal for changes in the existing regulations. Scenario analysis has been offered as a methodology that could be used to evaluate the variables contributing to the pest risk and to identify the options to mitigate the risk.

Background on the Pest:

PSB is the most destructive bark beetle of pines in Eurasia where it is a native pest. It can cause serious damage to the new growth of healthy trees as well as to weak and dying ones. Healthy trees are at risk when populations are high. It may also be an important vector of several diseases of pine. The current season's growth (shoots) of many species of pine serve as the primary hosts for feeding by adult beetles, while felled logs and downed trees are the primary breeding sites.

The pine shoot beetle has great potential to spread. Adults can fly 1 km., and the logs, nursery stock, Christmas trees and decorative foliage they infest are often transported long distances.

The pest has one generation per year. Adults begin overwintering in the Fall by boring short tunnels in and under the thick bark at the trunk of pine trees or in hollowed-out shoots. The adults emerge in the Spring when the daily temperature reaches 7-8°C (near 50°F). Beetles fly in the afternoons, with a peak between 3:00 and 6:00 in the afternoon. The male and female seek weakened trees, fresh stumps, or recently cut pine with bark more than 4-5 mm. thick to initiate gallery construction. Healthy trees may be attacked by breeding adults if population pressures are heavy.

Eggs (60 - 160) are laid singly in the gallery. Hatch is staggered over 14 to 21 days. Development from egg to adult averages 85 days, ranging from 55 days to 130 days. The adult parent beetles will stay in brood galleries for about 2 months. The parent beetles leave the galleries before emergence of the new generation and fly to the crowns of living pines where they bore into and feed in the shoots.

Females may produce a second brood of eggs in the same year after a period of feeding. This is known as a "sister brood," and develops 6-8 weeks later. Parent adults may overwinter a second time to produce another brood in the second year.

Larvae feed in the galleries under the bark until May or June when they mature into adults and then tunnel through the outer bark leaving 2 mm. wide exit holes. These new adults fly up into the upper part of the pine tree, as their parents did earlier, and bore into center of shoots (the tips of lateral branches from the current season's growth). They feed in the center of shoots, creating clean galleries from 4-9 cm. long. Each adult may destroy 3-6 shoots. Damaged shoots droop, become yellow to red, droop, and eventually fall to the ground. New generations continue to feed in the shoots until Fall when they hibernate.

Assessment Methodology:

In order to expedite the development of a pest risk assessment based on scenario analysis, a single expert meeting was organized to discuss scenarios and the evidence surrounding each event component. Five outside experts representing a range of experience and perspectives met with several PPQ staff personnel for 2½ days of discussion (technical background information was provided to experts in advance of the meeting). The results are summarized herein.

Figure 1 on page 4 describes the combination of scenarios determined to be the pathways for possible new outbreaks. Each pathway is demonstrated individually with its respective data in the section of the document devoted to the analysis of the probability data. Table 1 on page X begins this section with a summary of probability estimates developed by the expert group for each event and scenario. The product of point estimates for each scenario have been calculated and added to the summary table. Evidence and reference materials used or provided as the basis for estimates are listed in Appendix I.

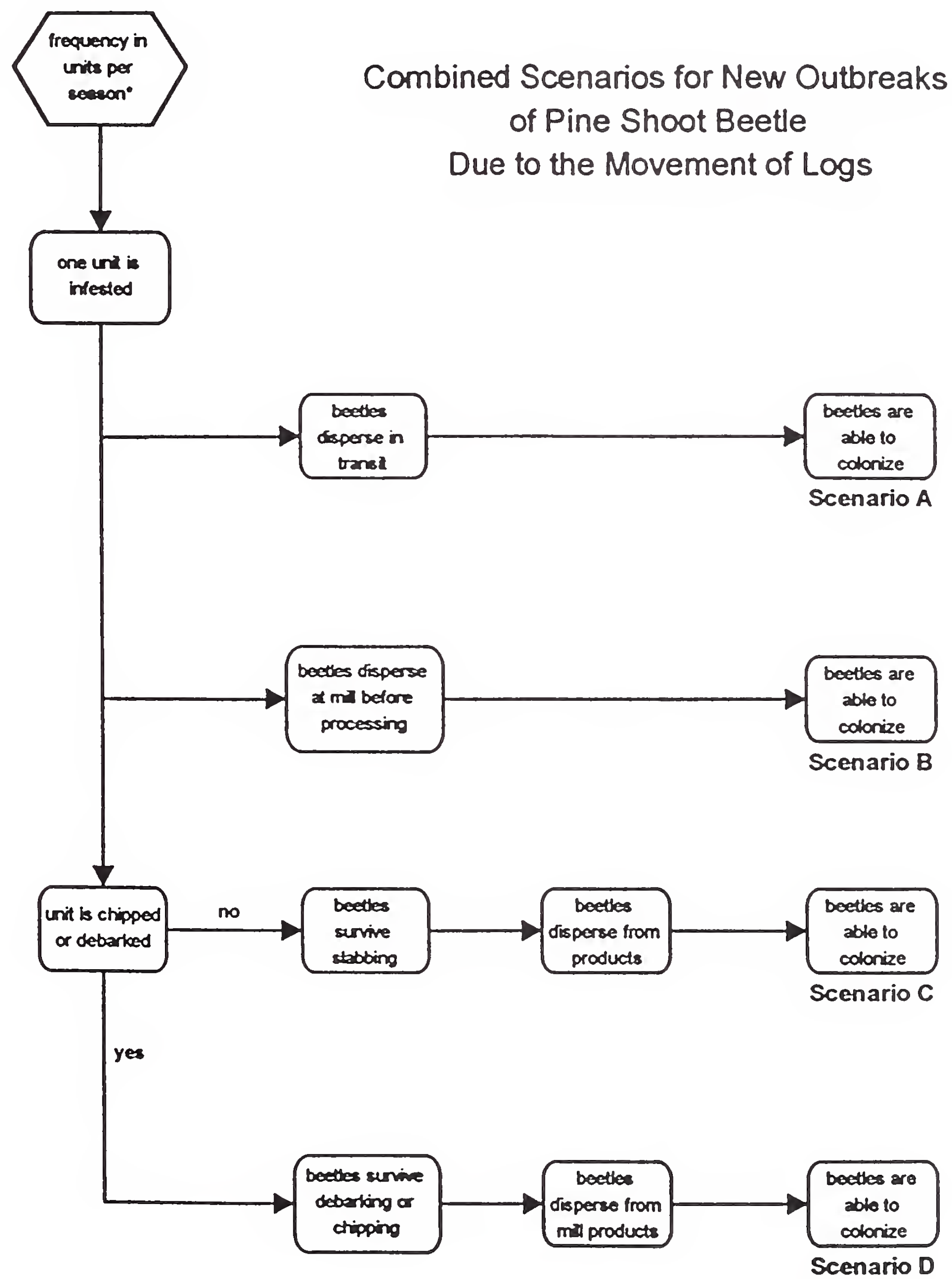
In each scenario, the most likely probability of any in the sequence of events occurring is represented by a point estimate and surrounded by an estimate of the lowest and highest probability in a triangular distribution. Experts were encouraged to estimate conservatively in order to ensure that the actual probability lies within the area of the curve defined by the estimates. A point estimate alone was used when the evidence indicated a very high degree of certainty. Estimates and continuing calculations of probability were terminated when any event resulted in the elimination of the pest risk.

It is important to note that estimates were based on Michigan data only. However, the probability estimates developed from Michigan data are believed to be generally representative of locations in the North Central and Northeast U.S. above 40° North Latitude.

By combining the curves for each event in a scenario pathway, an overall estimate of the risk and associated uncertainty were developed for scenarios describing the situation(s) as they would be without the addition of mitigation. This facilitated the identification of high risk scenarios and events. It also provided the background for evaluating the application and value of mitigation schemes applied to specific scenarios and events.

Tables 2, 3, and 4, and Figure 2 provide very useful interpretations of the data in terms of risk ranking, and comparative risk. Table 5 provides a summary of possible treatment measures and Table 6 summarizes mitigation applications.

Figure 1



*one unit = 100 trees

Introduction to Probability Data:

Each scenario (A, B, C, and D) has been analyzed according to seasons corresponding with the insect's activities (Summer, Fall, Winter, Early Spring, and Late Spring). This creates a total of 20 sub-scenarios. However, the summer sub-scenarios were determined by experts to have a negligible risk after the first event because insects would be feeding in shoots and therefore would not be associated with delimbed logs during this period. Eliminating the summer sub-scenarios brings the total number of sub-scenarios to 16.

Sub-scenarios are composed of several events (A1, A2, A3, etc.); probability distributions describe the frequency of each event. Each probability distribution is described by a point estimate that defines what experts believed to be the most likely value (the mode). Surrounding the point estimate are a high (maximum) and low (minimum) that describes the expert's uncertainty around the point estimate.

Expert consensus concerning the evidence determined that if point estimates were wrong, they would not be above the high value or below the low value. Thus, the high and low estimate for the frequency of each event create a triangular distribution around the point estimate and define the entire range of possible values. Experts were asked to estimate conservatively in order to ensure that there would be little likelihood that actual values would fall outside the distributions. Computer simulation using specially designed software[1] was used to graphically represent the distributions for each event and to calculate the product of all events for a scenario. Two types of curves were generated using Latin hypercube sampling and 3,000 to 9,000 iterations (trials with random numbers). One curve is roughly "bell-shaped" and demonstrates the distribution of probability across the range of values defined by the experts. The other curve is "s" shaped and demonstrates the cumulative probability from zero to 100%.

It should be noted that the values on the x axis of each graph are the log of the actual values (i.e., frequencies are shown on a log scale). The log scale is used to produce a more informative graph that facilitates interpretation. Note also that each graph is marked with a dotted line indicating the expected value (mean). The log value for the mean is noted in the upper left corner of each graph.

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[1] @ Risk by Palisade Software Inc., Newfield, New York

Assumptions:

1. All logs will be delimbed before being stacked in decks in the field.
2. All logs are normally completely processed within 4 weeks of felling.
3. Seasons are defined by felling date.
4. Normal stump cut is between 4 and 6 inches.
5. One unit = 100 trees = 10 cords
   Approximately 9,000 cords move from infested counties to non-infested counties per year in Michigan. Frequency = approximately 900 units per year evenly distributed by season.
6. Approximately half of logs go to chipping or debarking; half to slabbing.
7. No logs from Michigan move to destinations below the Mason-Dixon line.

Definition of Seasons: (based on the biology of the insect)

(Dates are relative to insect activities within the currently infested areas)

Fall	October 1 through December 15 Adults moving to overwintering sites or feeding in shoots.
Winter	December 16 through February 15 Beetles are overwintering, mostly in the base of standing trees, but some are in pine shoots on live trees. Normally no movement of beetles.
Early Spring	February 15 through April 30 Begins with spring flight and ends when all first broods have been initiated.
Late Spring	May 1 through June 30 Begins when all first broods have been initiated and ends when the last brood moves from the log.
Summer	July 1 through September 30 Parents and offspring are feeding in the shoots. No beetles are in logs or tree trunks.

General Information:

- Red, White, and Jack pine are native to the Great Lakes area. White pine is common in New York and Pennsylvania. Scotch pines are grown primarily as Christmas trees. Red and Scotch pine are good hosts for the Pine Shoot beetle. White and Jack pine are poor hosts.

- Dispersal of the Pine shoot beetle from mills and other processing facilities is defined as the movement of beetles outside the facility property. Therefore, the movement of beetles to materials within the processing facility does not constitute dispersion.

- Some logs harvested in Michigan may move by rail or barge. The additional handling associated with transferring logs from conveyances could result in a small increase in the risk of pest dispersion in transit if transfer points are outside of the regulated areas and no additional mitigation is added.

- Approximately equal percentages of pine are harvested in each season in Michigan.

- An average cord of Michigan harvested pine equals about 10 trees. Frequency estimates for the risk assessment are based on units equaling one hundred trees each.

- Harvested logs are sawn into lumber (rough and finished), chipped for pulp, or made into poles. Rough lumber that is formed from longitudinal sawing of logs may be stacked to air dry or may be kiln dried. Rough lumber will sometimes have bark attached to unfinished outside surfaces. The processes for producing lumber creates slabwood as a byproduct. Slabwood will normally have bark and is most frequently chipped and burned. Slabwood is also sometimes dried and sold as low-cost building material or it may be distributed as waste wood without drying.

- Chipping normally involves the entire log, including bark. Chips may be pulped for paper products or used whole in the production of composite materials such as chipboard. Bark that is removed separately (through debarking) is sorted into various sizes ranging from mulch (finest) to nuggets (largest). Bark products are commercially distributed for landscaping purposes.

- The processes used to produce poles remove all traces of bark and results in no slabwood.

Frequency:

Frequency is based on a unit equal to 100 trees. This unit is approximately equal to ten cords using ten trees per cord average in Michigan. One truckload of harvested logs is roughly eight cords. Therefore, a unit is somewhat more than an average truckload.

Information from the Michigan Department of Natural Resources indicates that about an equal percentage of pine is harvested during each of the four calendar seasons. Approximately 9,000 cords were harvested from infested counties in 1993. All of the logs harvested in infested counties were shipped to non-infested areas. This results in about 900 units/year, or an average of roughly 225 units per season moving from infested areas to non-infested areas.

The assessment sub-scenarios are divided according to seasons corresponding to the biological activities of the insect. These seasons do not correlate directly with calendar seasons in either length or number. Insect activities in early spring are significantly different than later in the season, resulting a two sub-scenarios for spring. Winter extends only two months, from December 16 through February 15, creating a sub-scenario of short duration.

The variability associated with assigning a calendar-based frequency to biologically defined seasons should be acknowledged when estimating or comparing the risk by season, but it is not a significant factor in estimating the risk for a unit over the entire year.

The most accurate and meaningful result was believed by the assessors to be provided by the annual estimate of risk. Consequently, point estimates based on a rough division of the frequency by calendar seasons were used to represent frequency. This was done to save time and simplify calculations. An alternative approach would prorate each seasonal estimate based on the length of time and expected conditions. Additional precision relative to seasonal estimates could be obtained by substituting more accurate estimates of the frequencies for biologically defined seasons.

The scenario discussions that follow are listed in the order defined by the scenario and grouped according to similarity in estimates. Each title describes the scenario(s) and seasons involved. Values in parenthesis following the title represent the low, most likely (point), and high estimate of probability developed by the expert group. The discussion section following each title provides a brief summary of information and citations to evidence considered relevant to the estimates.

Scenario Probability Summary Discussions

Sub-scenarios are identified for each discussion section, followed by the estimated values in parenthesis (low, point, high). A single value indicates that a probability distribution was not necessary because of the certainty associated with the estimate. A summary of all estimates is presented in Table 1 following the discussion sections.

Sub-scenarios A, B, C, & D - Summer probability that one unit is infested (0)

Based on the biology of the insect and the definition for the season, there is essentially zero probability that Pine Shoot beetle will be infesting logs without limbs. All beetles are feeding in the shoots during this time of year. This is described by the European literature and has been confirmed by observations of the U.S. Forest Service and APHIS Methods over a period of two summers in infested areas of the U.S.

No further estimate of the risk is necessary for this season. Any log harvested during summer and moved during the summer is essentially free of PSB and is therefore not considered to be the means for artificial spread of the pest.

Sub-scenarios A1, B1, C1, & D1 - Winter probability that one unit is infested (.05 - .5 - .8)

Beetles are overwintering in the base of trees. Most stands are assumed to be infested in areas where the pest is established but newly infested counties are assumed to be mostly beetle-free. This means that the probability estimate must be high, but cannot be 100%.

A 100-tree unit from an infested area would be expected to have some beetles present. As many as 150 beetles have been observed in one tree (no citation), but PPQ Methods observations indicate that 12-14 adults is average on Red pine with a 6" diameter. Experts agreed that it is feasible for 100 adults to be present in a single log.

Normal cutting practice would leave approximately 84% of the overwintering population in the stump if cut at 4" (2). Species such as white and jack pine are not good hosts but may be harvested, although not comprising a large percentage of the total.

Experts estimated that between 10 and 500 adult beetles would be present on an average unit, but a very small percentage of units might be beetle-free if from newly infested areas and/or comprised mainly of less suitable host species.

Sub-scenarios A1, B1, C1, & D1 - Early Spring probability that one unit is infested (.25 - .6 - .9)

Beetles are searching for and establishing brood sites during this period.

Spray efficacy testing done by APHIS Methods indicated that untreated control logs were infested without fail. Trap logs placed in infested areas in Michigan were also easily infested. Most attacks occur during March and April. Experts agreed that any suitable log available within the infested area would be very likely to be attacked, but that newly infested areas could have logs that were not.

Sub-scenarios A1, B1, C1, & D1 - Late Spring probability that one unit is infested (.05 - .2 - .4)

Attacks continue to a lesser extent through June. Observations made by Haack and Lawrence indicate lower levels of infestation in logs during late spring (3). The few beetles found in logs during late spring would be starting a second brood.

Sub-scenarios A1, B1, C1, & D1 - Fall probability that one unit is infested (.01 - .45 - .7)

Beetles are searching for and establishing overwintering sites. This period represents a transition from summer to winter. The probability of infestation must be smaller than the winter estimate because early fall logs are not as likely to be infested. The upper range of probability is defined by the rationale used for the winter estimate except that the value is slightly lower than winter because, by definition, infestation cannot be as high.

Sub-scenario A2 - Winter probability that beetles disperse in transit (.0001 - .0075 - .03)

The expert group assumed that some bark is knocked off logs during handling and transport. Some of the bark lost in transit will be from the base where beetles are overwintering if present. Based on observations, it is believed that beetles would not abandon a log voluntarily. Less than 1% of beetles infesting a unit would be expected to disperse as a result of this event, but dispersal is a function of the amount and kind of handling received.

Sub-scenario A2 - Fall probability that beetles disperse in transit (.0002 - .02 - .05)

Beetles are actively seeking overwintering sites during the Fall. Few beetles would be expected early in the season as most are feeding in shoots. As the season progresses, more beetles would be found on the outside of logs as they search for suitable overwintering locations. Later in the season, many would be expected to be hitchhikers on the outside of logs or overwintering in the base. The probability of dispersion must be less than that of winter because there is less likelihood that beetles will be on or in the log during this season.

Sub-scenario A2 - Early and Late Spring probability that beetles disperse in transit (.05 - .125 - .25)

Dispersal includes flight, walking, and being physically dislodged. Females stay 3-5 weeks in new fallen logs. All beetles present are parents except a rare F_1. The probability of dispersal in spring must be high because beetles are active and are exclusively associated with logs. Any part of the log could have beetles. Parent beetles will disperse by flight or walking as part of normal activities during this season. Rarely, new adults could emerge and become active (if logs were to remain unprocessed for 6 weeks).

Early and Late Spring have the same estimate because the same factors are involved in dispersal. However, the numbers of insects dispersing will be different (affecting colonization).

Sub-scenario B2 - Winter probability that beetles disperse from logs at a processing facility (.0001 - .0075 - .03)

Dispersal will probably be by flying or blowing. The dislodging of insects as a result of handling logs could cause some dispersal. An extended warm period during the winter could also cause insects to emerge and disperse. In either case, it is almost certain that reinfestation will occur within the processing facility due to the immediate presence of ample host material.

Sub-scenario B2 - Fall probability that beetles disperse from logs at a processing facility (.00001 - .00005 - .0001)

Beetles that are outside of logs will be attempting to enter or reenter (based on observations by PPQ Methods in Ohio). Fall is estimated to have a probability roughly 1/10 that of winter based on the low probability that Fall logs would be unprocessed by spring when beetles are more likely to disperse. There would be very little chance of broods starting or broods surviving from logs harvested in the Fall.

Sub-scenario B2 - Early and Late Spring probability that beetles disperse from logs at a processing facility (.05 - .1 - .3)

Approximately 10 weeks is required from felling to F_1 emergence and flight. In normal practice, processing would be accomplished within this timeframe. Dispersal is most likely to be from parents going to a second brood site or to feeding. The greatest hazard is associated with the dispersal of overwintering adults likely to start second broods. However, this will probably occur within the facility because of the availability of sites. Dispersal outside the yard is less likely, but there is a high degree of uncertainty around this estimate.

Sub-scenarios C2 and D2 - All Seasons; probability of logs going to chipping (0.5)

There is a high degree of accuracy around this estimate because it is based on recent empirical data. Approximately 50% of harvested logs are chipped or completely debarked (as done for pole production). The remaining 50% are slabbed.

Sub-scenario D3 - Fall, Winter, and Late Spring probability that beetles survive chipping or debarking (.002 - .01 - .05)

Observations by Haack indicate very poor chances of survival when heavily infested logs were chipped. The largest pieces of bark (nuggets) provide the greatest potential for survival but the probability was difficult to estimate in the absence of more data. The estimated range reflects the uncertainty.

Sub-scenario D3 - Early Spring probability that beetles survive chipping or debarking (.005 - .02 - .075)

Evidence, experience, and observations demonstrate that *Ips* species of bark beetles have not survived chipping to cause outbreaks. Experts agreed that this provides the basis for estimating the risk for PSB survival (a similar insect under similar circumstances) to be low. In addition, the chipping of infested Christmas trees has apparently been effective in controlling outbreaks based on experience to date. The estimate for Early Spring is somewhat higher than for other seasons because more adult beetles are actively associated with bark/logs.

Sub-scenario C3 - All seasons probability that beetles survive slabbing (.9 - .95 - .99)

Experts are certain that a very high percentage of beetles would survive slabbing. Approximately 5% of the beetle population in a log was believed by experts to be potentially at risk of being affected by slabbing. The primary reason is that the process of sawing is not rigorous enough to cause much mortality, although a few beetles may occasionally be affected.

Sub-scenario D4 - Fall and Winter dispersal of beetles from chips or bark (.001 - .0025 - .005)

Beetles surviving in chips and bark are less protected from the elements, becoming much more susceptible to fluctuations in heat and cold. Beetles are also more susceptible to predators and parasites. Chips and bark are normally pulped, burned, or mulched. All of these processes would result in total or nearly total mortality. The primary means for dispersal would be large bark nuggets, but this is believed by experts to be a very small risk.

Sub-scenario D4 - Early and Late Spring dispersal of beetles from chips and bark (.005 - .0175 - .05)

The estimate for Spring is somewhat higher than for fall and winter because a larger number of beetles will be associated with logs.

Sub-scenario C4 - Winter and Fall dispersal of beetles from slabwood and rough-cut lumber (.1 - .5 - .9)

This estimate indicates a very high probability for dispersal due to the potential for beetles to remain in cut wood with bark that is air dried or piled as waste, especially if left until spring. The highest risk is associated with slabwood that is not chipped or kiln dried, but rather stored or distributed in an uncontrolled manner. Mitigating circumstances that justify the low range value include burning, chipping, exposure of beetles to the elements and predators or parasites, kilning, planing, and bark removal.

Sub-scenario C4 - Early and Late Spring dispersal of beetles from slabwood and rough-cut lumber (.3 - .8 - .95)

This estimate is high because brood activity in slabwood with bark is essentially undisturbed.

Colonization Discussion:

The following points represent pertinent information raised during discussions of colonization:

- The potential for colonization in the U.S. was demonstrated in the 1920's when PSB was detected in a nursery in New Jersey. The outbreak was subsequently eradicated and the pest was not been detected again until recently.

- Slabwood has not been determined to be a factor in causing outbreaks around sawmills. This has been confirmed by limited surveys using trap logs around Michigan sawmills.

- PSB has been a commonly and frequently intercepted pest of imported wood for many years, with no outbreaks until recently.

- Point introduction requires finding suitable host material for starting a colony. This host material needs to be relatively freshly fallen (less than 7 months old) logs.

- The PSB has no pheromone for attracting the opposite sex. Therefore, potential mates must encounter each other on an acceptable log.

- Michigan ships Christmas trees to 38 States (over 900 locations). Some of these shipments occurred after the establishment of the pest but before it was detected. No outbreaks have been detected as a result of this activity.

- It is assumed that under normal circumstances, only a small number of insects will be dispersed at a point (eg. 5 males and 5 females).

Sub-scenario C5 - Early Spring colonization potential (.001 - .0225 - .5)

Based on the evidence and expert discussions, it is believed that the potential for colonization is relatively low for PSB. The expert group estimated that the upper limit for the probability of colonization would be no higher than 0.5, even though large numbers of beetles could be associated with slabwood under the best circumstances. The estimate is primarily a reflection of evidence indicating that outbreaks due to slabwood have not been observed in recent years, and the observed spread of the beetle appears to be natural.

Sub-scenario C5 - Fall, Winter, & Late Spring colonization potential (.0001 - .00225 - .05)

The probability of colonization for periods other than Early Spring in the C Scenario are estimated to be approximately 1/10th of the probability of the Early Spring Sub-scenario. The rationale for this reduction factor is essentially the same as for the A3, B3, and D5 estimates described below.

Sub-scenario A3, B3, & D5 - Fall, Winter, and Late Spring colonization potential (.000001 - .00001 - .0001)

The probability of colonization during these periods is estimated to be very low because dispersing adults must survive until breeding time. This is believed to be highly unlikely considering the rigors of the environment, the perils of exposure, and the activity cycle of the insect during these periods.

Sub-scenario A3, B3, & D5 - Early Spring colonization potential (.00001 - .0001 - .001)

The estimates for the probability of colonization in the A, B, and D scenarios are much lower than for the C scenario, primarily because the numbers of insects dispersing at a point is much smaller.

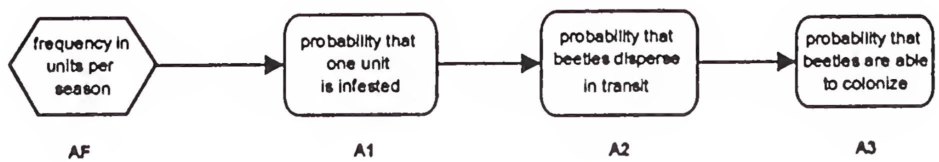
Table 1: Combined Probability Estimates - All Scenarios for Pine Shoot Beetle/Logs

	Summer	Fall			Winter			Early Spring			Late Spring		
	point	low	point	high	low	point	high	low	point	high	low	point	high
AF	225		225			225			112.5			112.5	
A1	0	0.01	0.45	0.7	0.05	0.5	0.8	0.25	0.6	0.9	0.05	0.2	0.4
A2		0.0002	0.02	0.05	0.0001	0.0075	0.03	0.05	0.125	0.25	0.05	0.125	0.25
A3		1E-06	1E-05	0.0001	1E-06	1E-05	0.0001	1E-05	0.0001	0.001	1E-06	1E-05	0.0001
pt. prod.			2E-05			8.4E-06			0.000844			2.81E-05	
BF	225		225			225			112.5			112.5	
B1	0	0.01	0.45	0.7	0.05	0.5	0.8	0.25	0.6	0.9	0.05	0.2	0.4
B2		1E-05	5E-05	0.0001	0.0001	0.0005	0.001	0.05	0.1	0.3	0.05	0.1	0.3
B3		1E-06	1E-05	0.0001	1E-06	1E-05	0.0001	1E-05	0.0001	0.001	1E-06	1E-05	0.0001
pt. prod.			5.1E-08			5.6E-07			0.000675			2.25E-05	
CF	225		225			225			112.5			112.5	
C1	0	0.01	0.45	0.7	0.05	0.5	0.8	0.25	0.6	0.9	0.05	0.2	0.4
C2			0.5			0.5			0.5			0.5	
C3		0.9	0.95	0.99	0.9	0.95	0.99	0.9	0.95	0.99	0.9	0.95	0.99
C4		0.1	0.5	0.9	0.1	0.5	0.9	0.3	0.8	0.95	0.3	0.8	0.95
C5		0.0001	0.00225	0.05	0.0001	0.00225	0.05	0.001	0.0225	0.5	0.0001	0.00225	0.05
pt. prod.			0.054105			0.060117			0.577125			0.019238	
DF	225		225			225			112.5			112.5	
D1	0	0.01	0.45	0.7	0.05	0.5	0.8	0.25	0.6	0.9	0.05	0.2	0.4
D2			0.5			0.5			0.5			0.5	
D3		0.002	0.01	0.05	0.002	0.01	0.05	0.005	0.02	0.075	0.002	0.01	0.05
D4		0.001	0.0025	0.005	0.001	0.0025	0.005	0.005	0.0175	0.05	0.005	0.0175	0.05
D5		1E-06	1E-05	0.0001	1E-06	1E-05	0.0001	1E-05	0.0001	0.001	1E-06	1E-05	0.0001
pt. prod.			1.3E-08			1.4E-08			1.2E-06			1.97E-08	

Scenario Sum	
sum A	0.000901
sum B	0.000698
sum C	0.710585
sum D	1.2E-06
total	0.712185

Season Sum for Scenario "C"	
fall	0.054126
early spring	0.578644
late spring	0.019288
winter	0.054126
total	0.706183

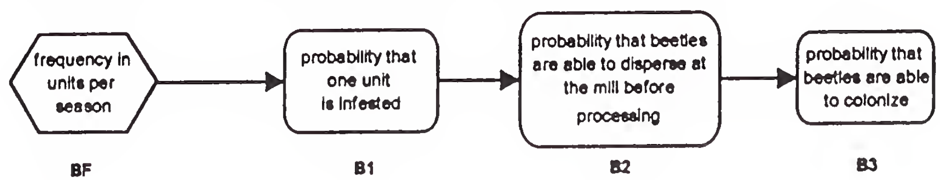
Scenario A: Dispersal in Transit



Combined Probability Estimates and Point Products for Scenario A

event	summer	fall			winter			early spring			late spring		
	point	low	point	high	low	point	high	low	point	high	low	point	high
AF	225		225			225			112.5			112.5	
A1	0	0.01	0.45	0.7	0.05	0.5	0.8	0.25	0.6	0.9	0.05	0.2	0.4
A2		0.0002	0.02	0.05	0.0001	0.0075	0.03	0.05	0.125	0.25	0.05	0.125	0.25
A3		1E-06	1E-05	0.0001	1E-06	1E-05	0.0001	1E-05	0.0001	0.001	1E-06	1E-05	0.0001
pt. prod.			2E-05			8.4E-06			0.000844			2.8E-05	

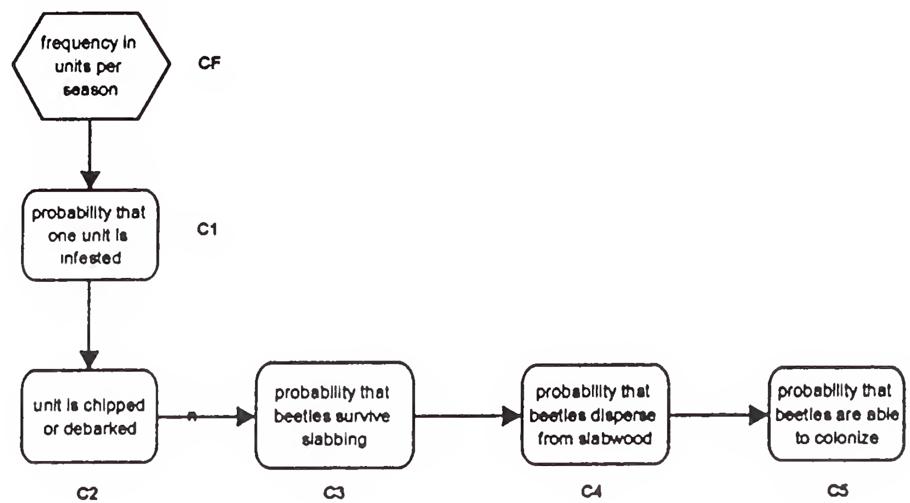
Scenario B: Dispersal at the Mill before Processing



Combined Probability Estimates and Point Products for Scenario B

event	summer	fall			winter			early spring			late spring		
	point	low	point	high	low	point	high	low	point	high	low	point	high
BF	225		225			225			112.5			112.5	
B1	0	0.01	0.45	0.7	0.05	0.5	0.8	0.25	0.6	0.9	0.05	0.2	0.4
B2		1E-05	5E-05	0.0001	0.0001	0.0005	0.001	0.05	0.1	0.3	0.05	0.1	0.3
B3		1E-06	1E-05	0.0001	1E-06	1E-05	0.0001	1E-05	0.0001	0.001	1E-06	1E-05	0.0001
pt. prod.			5.1E-08			5.6E-07			0.000675			2.3E-05	

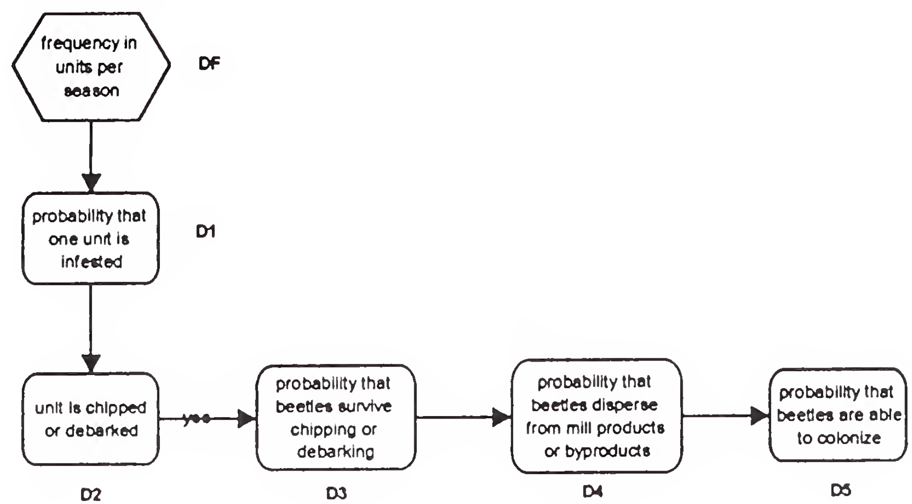
Scenario C: Dispersal from Slabwood



Combined Probability Estimates and Point Products for Scenario C

event	summer	fall			winter			early spring			late spring		
	point	low	point	high	low	point	high	low	point	high	low	point	high
CF	225		225			225			112.5			112.5	
C1	0	0.01	0.45	0.7	0.05	0.5	0.8	0.25	0.6	0.9	0.05	0.2	0.4
C2			0.5			0.5			0.5			0.5	
C3		0.9	0.95	0.99	0.9	0.95	0.99	0.9	0.95	0.99	0.9	0.95	0.99
C4		0.1	0.5	0.9	0.1	0.5	0.9	0.3	0.8	0.95	0.3	0.8	0.95
C5		0.0001	0.00225	0.05	0.0001	0.00225	0.05	0.001	0.0225	0.5	0.0001	0.00225	0.05
pt. prod.			0.054105			0.060117			0.577125			0.019238	

Scenario D: Dispersal from Mill Product

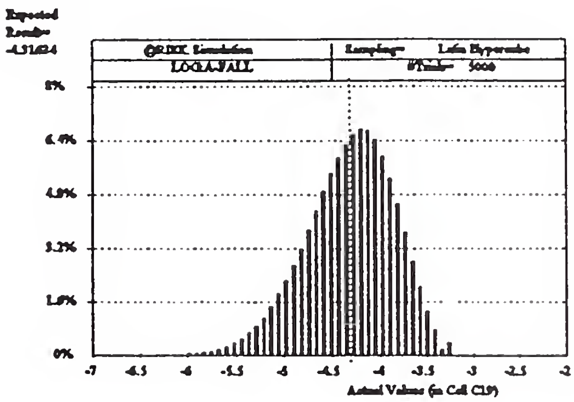


Combined Probability Estimates and Point Products for Scenario D

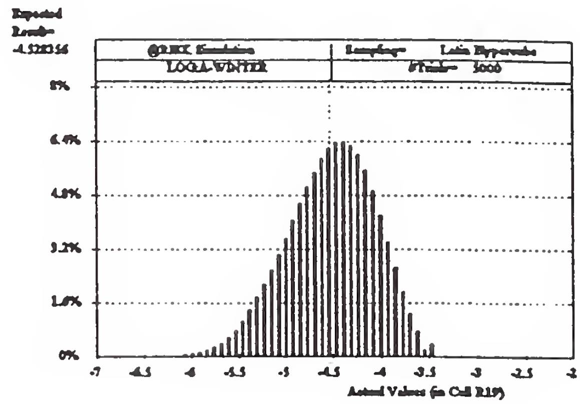
event	summer	fall			winter			early spring			late spring		
	point	low	point	high	low	point	high	low	point	high	low	point	high
DF	225		225			225			112.5			112.5	
D1	0	0.01	0.45	0.7	0.05	0.5	0.8	0.25	0.6	0.9	0.05	0.2	0.4
D2			0.5			0.5			0.5			0.5	
D3		0.002	0.01	0.05	0.002	0.01	0.05	0.005	0.02	0.075	0.002	0.01	0.05
D4		0.001	0.0025	0.005	0.001	0.0025	0.005	0.005	0.0175	0.05	0.005	0.0175	0.05
D5		1E-06	1E-05	0.0001	1E-06	1E-05	0.0001	1E-05	0.0001	0.001	1E-06	1E-05	0.0001
pt. prod.			1.3E-08			1.4E-08			1.2E-06			2E-08	

Probability Distribution Curves

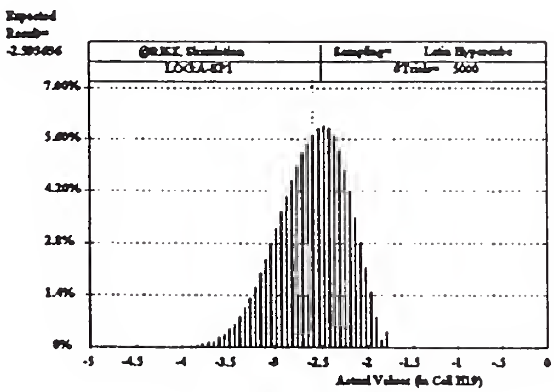
Scenario A - Fall



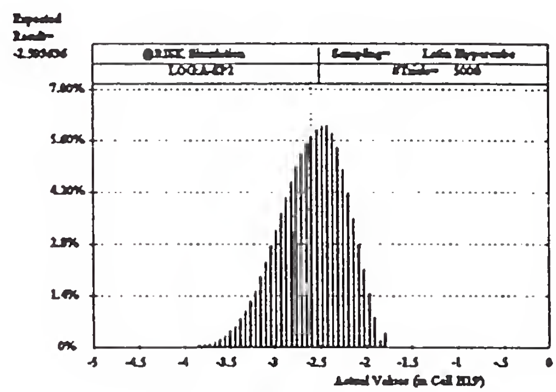
Scenario A - Winter



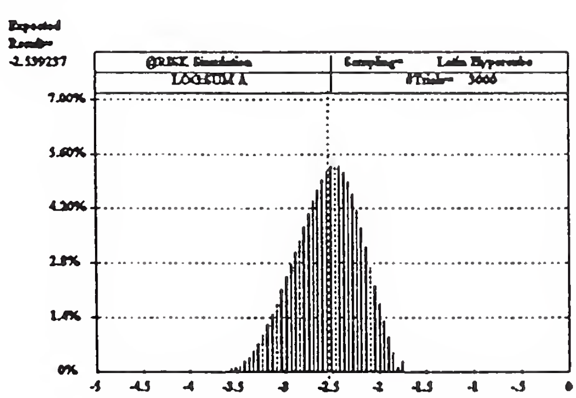
Scenario A - Early Spring



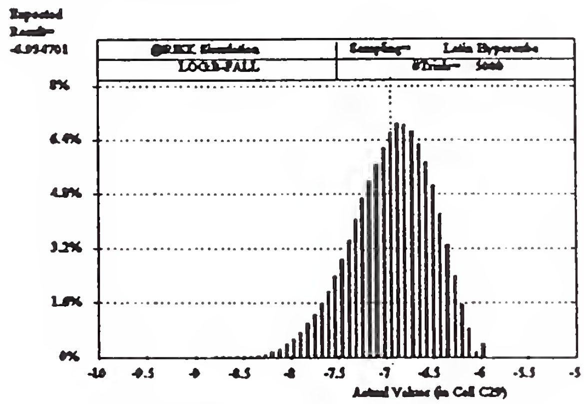
Scenario A - Late Spring



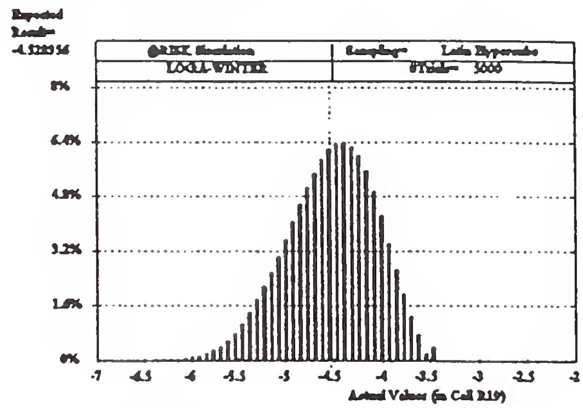
Scenario A - All Seasons



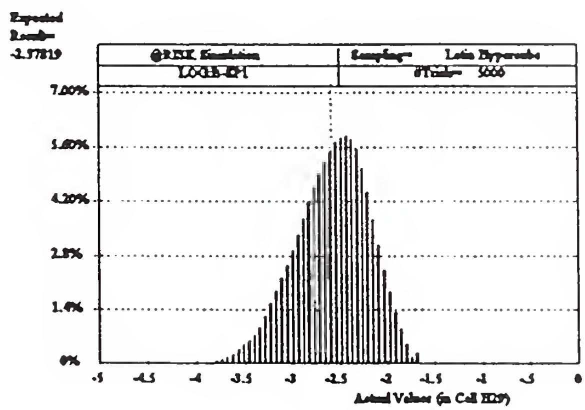
Scenario B - Fall



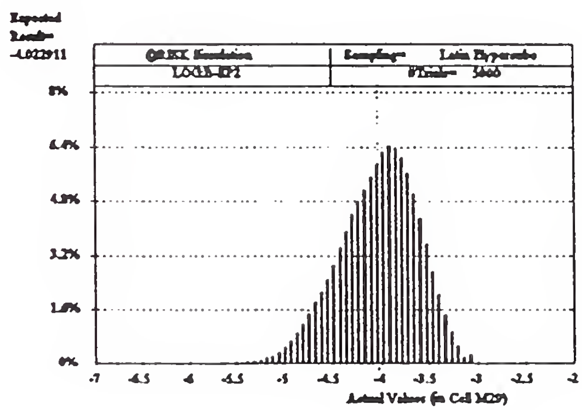
Scenario B - Winter



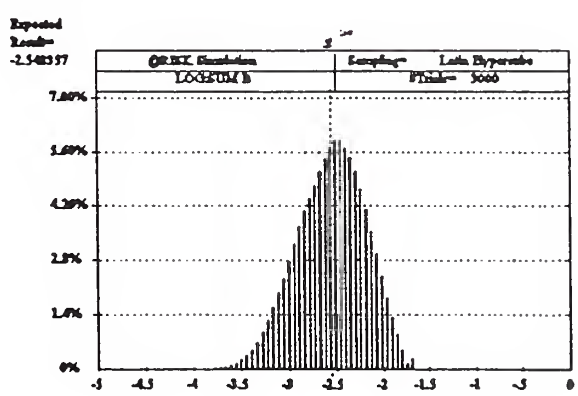
Scenario B - Early Spring



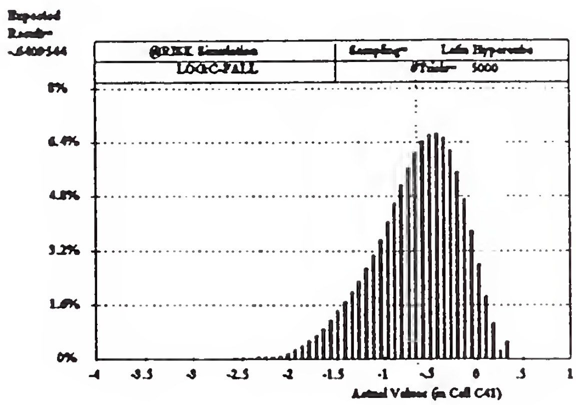
Scenario B - Late Spring



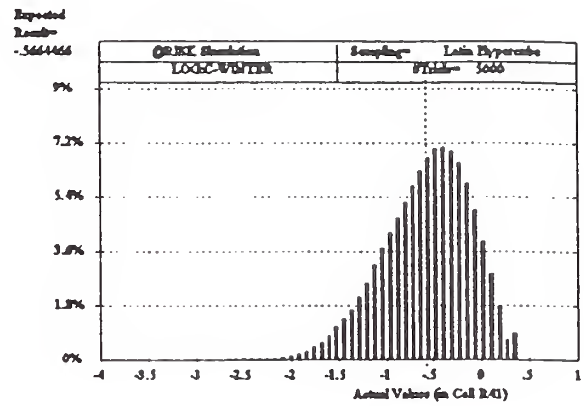
Scenario B - All Seasons



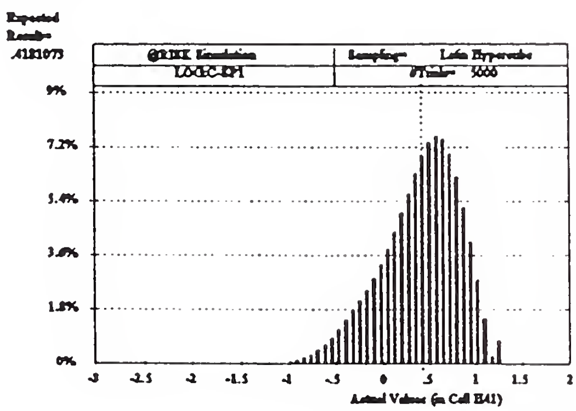
Scenario C - Fall



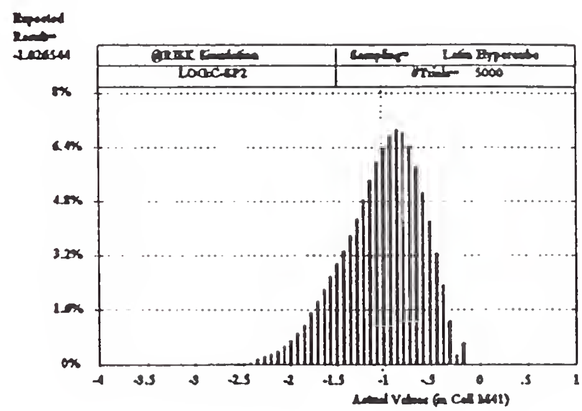
Scenario C - Winter



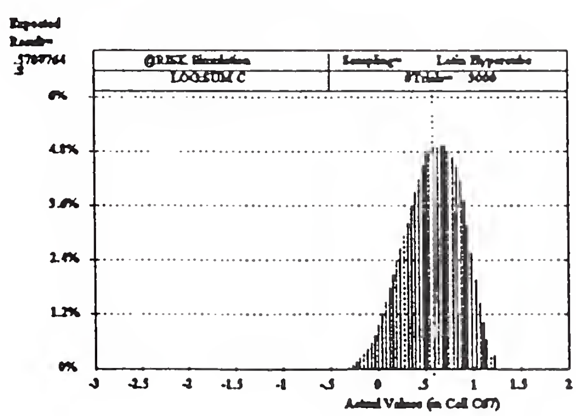
Scenario C - Early Spring



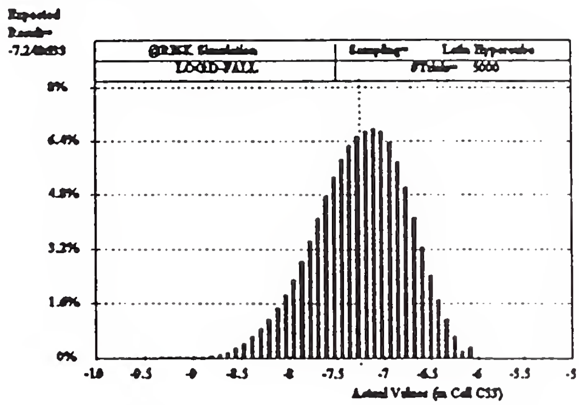
Scenario C - Late Spring



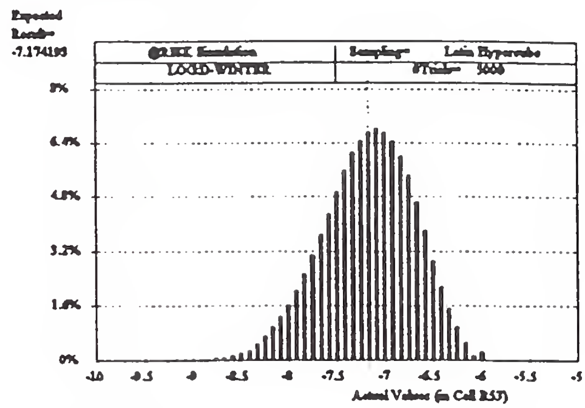
Scenario C - All Seasons



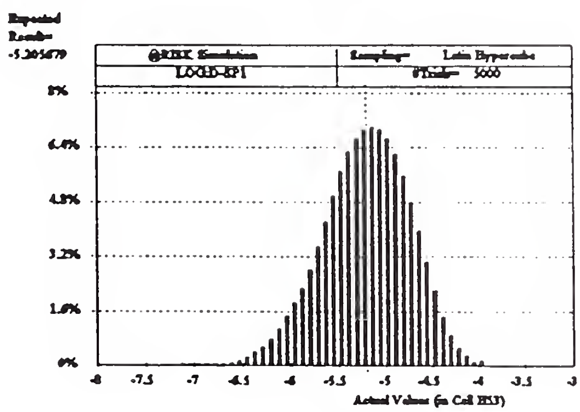
Scenario D - Fall



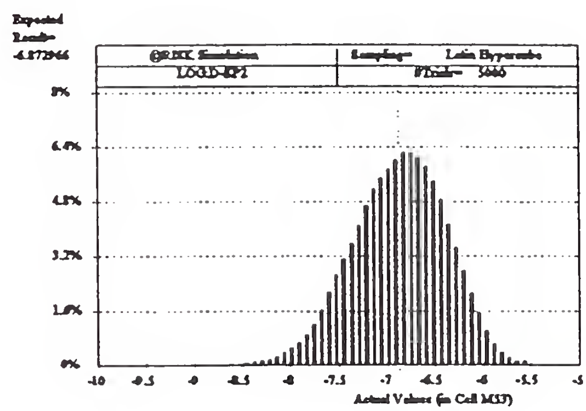
Scenario D - Winter



Scenario D - Early Spring



Scenario D - Late Spring



Scenario D - All Seasons

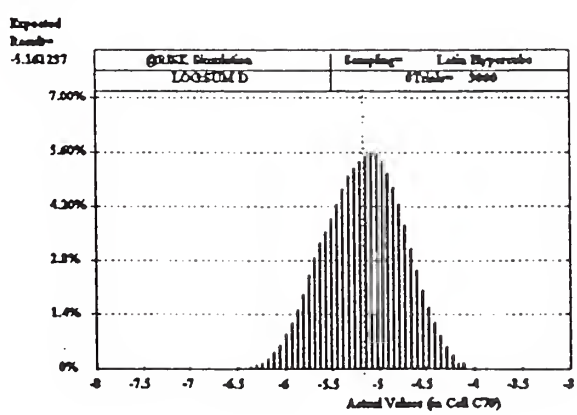


Table 2: Frequency of Outbreaks by Season and Years per Outbreak

Dispersal from:		Fall	Winter	Early Spring	Late Spring	New Outbreaks/Yr	Years/Outbreak
Scenario A Transit	mean	7.86E-05	4.68E-05	0.00344	0.000127	0.0036924	270.83
	mode	2E-05	8.4E-06	0.000844	2.81E-05	0.0009005	1110.49
	95%	0.000223	0.000137	0.0088	0.00033	0.00949	105.37
Scenario B The Mill	mean	1.73E-07	1.98E-06	0.00365	0.000135	0.003787153	264.05
	mode	5.1E-08	5.6E-07	0.000675	2.25E-05	0.000698111	1432.44
	95%	4.75E-07	5.28E-06	0.00958	0.00036	0.009945755	100.55
Scenario C Slabwood	mean	0.36	0.421	3.71	0.138	4.629	0.22
	mode	0.054105	0.060117	0.577125	0.19238	0.883727	1.13
	95%	1	1.21	9.22	0.369	11.799	0.08
Scenario D Mill Byproducts	mean	9.35E-08	1.1E-07	9.85E-06	2.25E-07	1.02785E-05	97290.46
	mode	1.3E-08	1.4E-08	1.2E-06	1.97E-08	1.2467E-06	802117.59
	95%	2.83E-07	3.37E-07	2.89E-05	7.12E-07	3.0232E-05	33077.53
All Scenarios by Season	mean	0.3601	0.4210	3.7171	0.1383	4.6365	0.2157
	mode	0.0541	0.0601	0.5786	0.1924	0.8853	1.1295
	95%	1.0002	1.2101	9.2384	0.3697	11.8185	0.0846

Table 3: Percent Risk by Scenario and Season Using the Mode Value

	Fall	Winter	Early Spring	Late Spring	Sum
Scenario A	0.002259	0.000949	0.09533211	0.00317397	**0.1017**
Scenario B	5.8E-06	6.3E-05	0.0762431	0.00254144	**0.0789**
Scenario C	6.111308	6.79038	65.1878517	21.7298487	**99.8194**
Scenario D	1.5E-06	1.6E-06	0.00013554	2.2252E-06	**0.0001**

Figure 2: Comparative Risk

Based on Mode Values

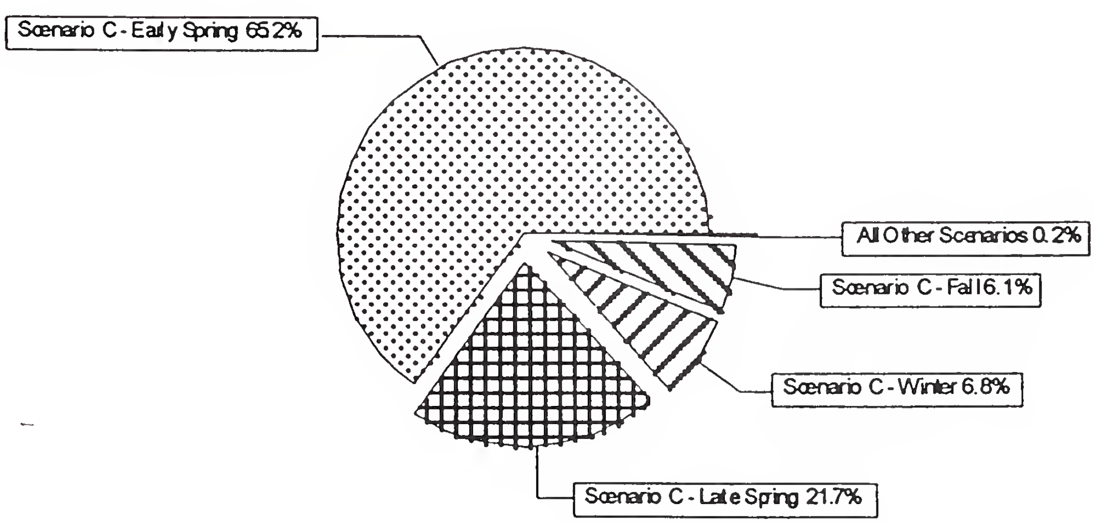


Table 4: Sub-scenario Ranking byRisk Based on Mode Values

	Product of Point Estimate	Scenario
lowest probability	.000000013 (1.3×10^{-8})	Fall dispersal from chips and bark at the mill site
	.000000014 (1.4×10^{-8})	Winter dispersal from chips and bark at the mill site
	.000000020 (2.0×10^{-8})	Late Spring dispersal from chips and bark at the mill site
	.000000051 (5.1×10^{-8})	Fall dispersal from logs at the mill before processing
	.00000056 (5.6×10^{-7})	Winter dispersal from logs at the mill before processing.
	.0000012 (1.2×10^{-6})	Early Spring dispersal from chips and bark at the mill site
	.0000084 (8.4×10^{-6})	Winter dispersal from logs in transit
	.00002 (2.0×10^{-5})	Fall dispersal from logs in transit
	.000023 (2.3×10^{-5})	Late Spring dispersal from logs at the mill before processing
	.000028 (2.8×10^{-5})	Late Spring dispersal from logs in transit
	.000675 (6.75×10^{-4})	Early Spring dispersal from logs at the mill before processing
	.00084 (8.4×10^{-4})	Early Spring dispersal from logs in transit
	.019	Late Spring dispersal from slabwood and rough-cut lumber at the mill site
	.054	Fall dispersal from slabwood and rough-cut lumber at the mill site
	.06	Winter dispersal from slabwood and rough-cut lumber at the mill site
highest probability	.57	Early Spring dispersal from slabwood and rough-cut lumber at the mill site

Mitigation Discussion

[incomplete - to be inserted]

Listing of Potential Risk Management Recommendations:

1. No restrictions on total tree utilization or logs and lumber without bark.

2. Allow movement from regulated counties without restrictions if harvested after June 30 and moved from the regulated area before Sept. 30.

3. Allow movement from regulated areas after fumigation anytime. However:

   a.) Logs and lumber with bark must be protected from reinfestation at the harvest site or within 300 feet of pine trees if treated between Oct. 1 and Dec. 15.
   b.) Logs and lumber with bark must be protected from reinfestation anywhere within the regulated area between Feb. 15 and June 30.

4. Allow movement from regulated areas with butt cutting if stump and butt cut total 6 to 8 inches and trees are harvested after Dec. 15 and moved outside the regulated area before Feb. 15.

5. Allow delayed movement if log or lumber with bark is from trees harvested before June 30 and moved from the regulated area after Oct. 1.

6. Lumber with bark is not restricted if kiln dried, or air dried for at least 6 months.

7. Logs and lumber with bark can move to approved facilities if harvested after June 30 and moved outside regulated areas before Feb. 15.

8. Logs and lumber with bark from trees harvested after October 1 must be completely processed by approved mills within 4 weeks of harvest. Complete processing includes:

   a.) all bark on lumber is removed or lumber is kiln dried
   b.) all bark is burned, shredded, chipped, pulped, or fumigated
   c.) all logs are debarked
   d.) all slabwood is burned or chipped

9. Logs and lumber with bark from regulated areas, commingled with logs and lumber with bark from unregulated areas, must be handled by approved mills under the restrictions that apply to logs from regulated areas. Mills approved to receive logs and lumber with bark from regulated areas must be located in the currently infested States, or States located completely above 40° N Latitude.

10. Regulate bark nuggets and bark chips from infested counties.

Table 5: Potential Treatment Measures

1. Prohibit movement of logs	
2. Fumigation	a) of logs at the deck in the field
	b) of logs at the mill site
	c) of bark and chips
3. Debarking	a) in the field
	b) at the mill site
4. High stumping (leaving at least 6" or 8")	
5. Butt-cutting (equal to leaving 6" to 8" total)	
6. Total tree utilization (complete chipping in the field)	
7. Insecticide spray	a) at deck in the field
	b) at the mill site
8. Delayed movement (fell in spring- move in summer, fall, or winter)	
9. Destruction	a) by consumption (burning)
	b) by processing (pulping, kiln drying, chipboard manufacture, , etc.)

Table 6: Mitigation Applications

Logs and lumber with bark can move outside the regulated area between ...	**... if one of the following**
July 1 and Sept. 30	harvested between July 1 and Sept. 30
	fumigated
	moved to an approved facility
Oct. 1 and Dec. 15	fumigated
	harvested before July 1
	moved to an approved facility
Dec. 16 and Feb. 15	fumigated
	moved to an approved facility
	stump and butt cut total 6" (?)
Feb. 16 and June 30	fumigated
	moved to an approved facility

Appendix I: Evidence

(1) Langstrom, B. 1980. Life cycles of the pine shoot beetles with particular reference to their maturation feeding in the shoots of Scots pine. Ph.D. Dissertation, Swedish University of Agricultural Sciences, Faculty of Forestry, Division of Forest Entomology. Garpenburg, Sweden.

(2) Haack, R.A., and R.K. Lawrence. 1994. *Tomicus piniperda* in the Great Lakes region: published and unpublished research results. Material presented to the Pine Shoot Beetle Conference, Lansing, Michigan, 29 June 1994.

(3) Haack, R.A., and R.K. Lawrence. 1994. Attack densities of *Tomicus piniperda* and *Ips pini* (Coleoptera: Scolitidae) on Scotch pine logs in Michigan in relation to felling date. For publication in the Journal of Entomological Sciences. (in press)

(4) Haack, R.A. and R.K. Lawrence. 1994. Spring flight of *Tomicus piniperda* in relation to native Michigan pine bark beetles and their associated predators. In F.P. Hain, H. Saarenmaa, F.W. Ravlin, and T.L. Payne[eds], Behavior, population dynamics, and control of forest insects, Proceedings of the joint IUFRO conference for Working Parties S2.07-05 and S2.07-06, Maui, Hawaii, 6-11 February 1994. Ohio State University Press, Columbus, Ohio. (in press)

(5) Haack, R.A. 1993. Exotic forest insects and diseases in North America: Patterns and recent arrivals. Presented to the North American Forestry Commission, Forest Insect and Disease Working Group, Veracruz, Mexico, 13-15 October 1993.

(6) USDA. 1972. Insects not known to occur in the United States: A bark beetle (*Tomicus piniperda* (Linnaeus)).

(7) 18 August 1994. Personal communication by fax from Frank J. Sapio, Michigan Department of Natural Resources, providing requested data concerning pine harvesting in Michigan.

(8) 17 August 1994. Personal communication by fax from Frank J. Sapio, Michigan Department of Natural Resources, providing requested data concerning pine harvesting in Michigan.

(9) Expert group judgement, experience, or observation.

Assessors

Robert L. Griffin
Plant Pathologist
USDA, APHIS, PPD, PRAS

C. Ed Miller
Entomologist
USDA, APHIS, PPD, PRAS

Primary Expert Group

Deb McCullough
Research Entomologist
Michigan State University

Bob Haack
Research Entomologist
U.S. Forest Service

Win McLane
Regulatory Methods Development Specialist
USDA, APHIS, S&T

Mike Likens
Regulatory Plant Pathologist
Virginia Department of Agriculture

Raj Sitaraman
Regulatory Entomologist
Michigan State Department of Agriculture